ORIGINAL ARTICLE

Experiments,methods of applying grouted jetted precast concrete sheet piles

XIAO Wen-wei

Puyang Economic Development Zone Construction Project Safety Production Supervision and Management Station,Pu yang City,457000,China

Abstract: Grouted jetted precast concrete piling is definitely an innovative technology that enhances the efficiency of piling operations in coastal regions.We have includes casting concrete piles factory,jetting to operate a vehicle the concrete piles with a crane over a floating ship or platform into soil,and grouting to further improve the sheet pile connections and raise the pile bearing capacity.This technology was put on many piling construction projects at the mouth from the Yellow River Delta in China.This experience demonstrated that it's a robust,fast track,cost-effective,and environmentally friendly piling method.

Keywords: Jetting,piling technique,retaining walls,sheet pile,coastal infrastructure,Yellow River.

Introduction

The use of water jetting is definitely an effective way of driving piles into soil,particularly firm clay,sands,or loose gravel.Jetting can be used driving concrete or heavy timber piles and sheet piles including wide flange,T-shaped,or similar concrete sheet piles.This is a relatively quiet driving process because no shake the ground.Besides,it can also help to attenuate problems for piles in hard clay or dense sand.It needs to be particularly suitable for construction is employed in coastal regions,where water is plentiful for jetting.Seawater brings jetting,and its use doesn't have noticeable effect on natural environment.

To increase pile bearing capacity,jetting is not allowed for the ultimate impact driving.Instead,conventional impact driving techniques are used for the last setting of jetted piles.Other techniques seemed to be used.For example,filling boulders,cobbles,and coarse gravels in the loose zone between the pile and also the surrounding soil was used to increase the pile bearing capacity.

These methods for enhancing the bearing capacity of jetted piles cost a lot and frustrating.It's also difficult to predict the pile bearing capacity of jetted piles and also to achieve satisfactory treating the filling of huge hard materials inside the loose zone.Impact-driven piles are reported to own better load-bearing features than jetted-driven piles under comparable soil conditions,though they will often cause failures in soft soils.

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is properly cited.

Grouted jetted precast sheet piling method is to solve the bearing capacity issue associated with conventional pile jetting in coastal regions.This new jetting technique retains is generally considerably the standard jetting technique since its quietness minimizes disturbance towards the soil round the pile.Furthermore,it firmly connects adjacent sheet piles and to help the shear strength in the disturbed soil zone close to the jetted pile.

1. Grouted jetted precast concrete sheet piling method

1.1 General

The typical jetting technique uses a straight jetting pipe having a single nozzle at its tip to disturb and weaken the soil and lead the pile in the weakened ground by gravity.The water jet spreads into the soil in the form of a cone(Fig.1a).This jetting method disturbs and weakens the soil round the pile,producing lower pile bearing capacity.

From the new jetting technique,the jetting pipe is incorporated from the pile(Fig.1a)or even the sheet pile(Fig.1b).Rather than a single nozzle(Fig.1a),a large number of smaller nozzles(Fig.1b)can be used jetting water.The river is jetted through the small holes with the pile toe by means of a uniform rectangular column.Therefore,the soil beneath and adjacent to the sheet pile toe might be vertically cut.The disturbed gap relating to the sheet pile as well as the undisturbed soil is relatively small,typically 10-20 mm wide.

1.2 Set up

The grouted jetted piling method consists of a floating platform using a crane to lift the piles as well as pump systems(Fig.2).The pile sinks vertically into water and soil in the chosen position by its own weight.One of many two pump systems is for jetting water and the other one is for grouting.The sheet pipe features a central pipe for jetting.

1.3 Concrete sheet pile special features

Besides the normal reinforcement,the precast concrete sheet pile design includes several nonstandard items.

1.4 Central pipe

The sheet pile features a steel pipe along its central axis(Fig.3).The pipe is open at the pile head for hitting the ground with a plastic hose and transfers pressured water from your hose to the pile toe.

1.5 Toe nozzle pipe

The pile toe has a steel pipe inside the horizontal direction for jetting water in the soil the location where the pile is to be inserted.This toe pipe contains a lot of regularly spaced holes about 3 mm in diameter.The central pipe is connected with the toe pipe.Water from your central pipe is directed in to the toe nozzle pipe and it is jetted over the small holes in to the soil.

1.6 I-beam

A steel I-beam is partially cast inside the concrete sheet pile along certainly one of its sides.The I-beam is between two semicircular channels.

1.7 Rectangular tube

A steel tube with rectangular cross-section(rectangular tube)is cast inside the concrete sheet pile along the side opposite towards the I-beam.The oblong tube features a narrow opening slightly thicker than the I-beam web but narrower as opposed to I-beam flanges.The interior width of the rectangular tube is slightly greater than the width in the I-beam flange.

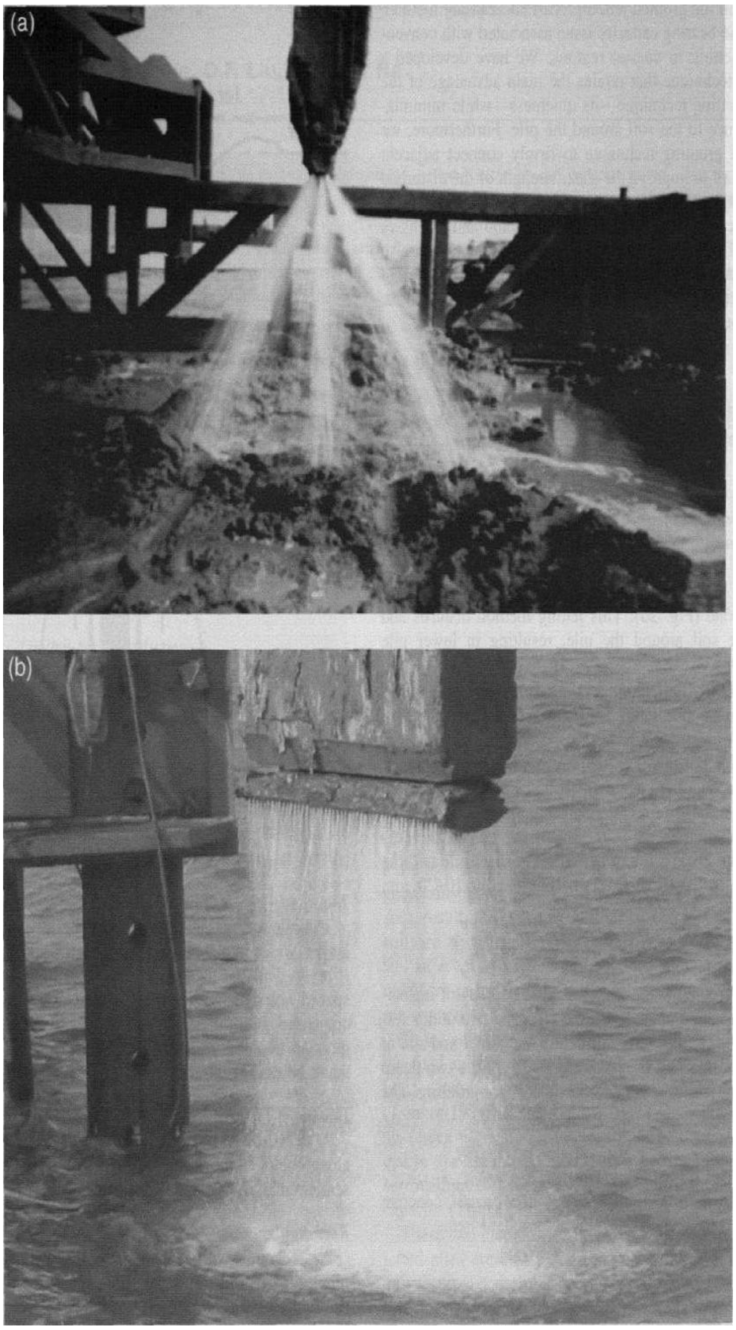


Fig.1 New jetting water from internal pipe within piles.(a)Jetting water derived from one of nozzle with a toe of the pile in the form of a cone.(b)Jetting of water from many smaller nozzles with a concrete sheet pile toe by means of many downward flow sines rich in speed

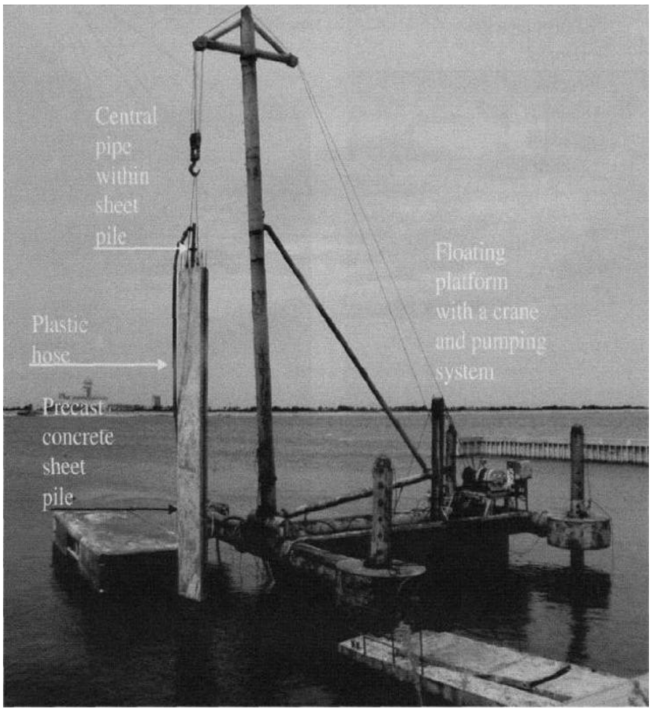


Fig.2 General view of the grouted jetted precast concrete sheet piling method

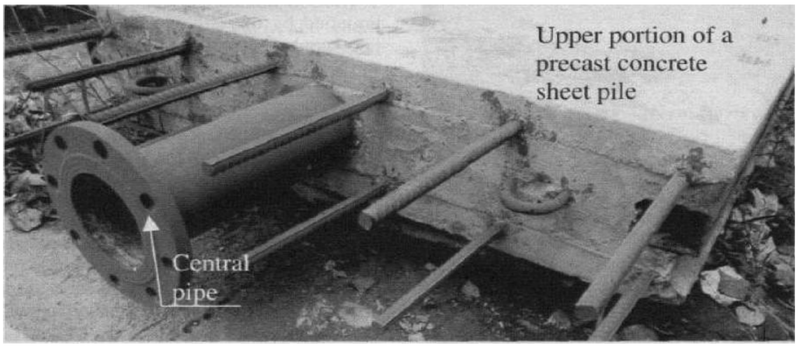


Fig.3 Central pipe in precast concrete sheet pile for jetting and steel reinforcements for connection

1.8 Jetting for pile driving

If the sheet pile is erected on the right position,water pressurized is pumped in to the vertical central pipe using a plastic hose.The plastic hose is connected to a series of small nozzles with the pile toe,which jet the water to the soil(Fig.1b).The pumping pressure is all about 1.5 to 2 MPa.The complete water discharge minute rates are about 50-80 Lis.

To make sure that small holes at the pile toe tend not to become blocked with sand or gravel,the water for pumping and jetting should not contain any solid particles.Our experience suggests that the information of solid particles inside the water shouldn't be greater than 1%of the total water weight.

The soil immediately underneath the pile toe is loosened and liquefied from the jetting action,enabling the concrete sheet pile and controlled from the crane to sink into it by its weight.The crane operator continues jetting prior to the pile reaches the structure depth.When the pile sinks to a point about 0.5 m above its design depth,he reduces the water discharge rate and water pressure to be able to minimize soil disturbance beneath the permanent pile toe.

Once the first pile may be installed,an identical process is used to put in the next pile.Before jetting,the free flange from the I-beam using one vertical side face of the second sheet pile needs to be inserted in to the rectangular tube one vertical side face in the first sheet pile.The free flange from the second pile I-beam fits within the rectangular tube of the first sheet pile.This procedure is repeated wonderful subsequent piles.

Fig.4 illustrates the pile installation technique.This technique reduces the width of the disturbed soil zone adjacent to the pile.Our experience has shown that the disturbed soil zone width is in the order of 10–20 mm.

2. Grouting for sheet pile connection

As described above,two sheet piles are installed side by side in the ground.One of many two I-beam flanges of the second sheet pile is inserted to the rectangular tube in the first sheet pile.The attached four semicircular channels of these two sheet piles form two vertical cylindrical holes whose cross-sections A–A'and B–B'are shown in Fig.5.

Inevitably,the cylindrical holes,steel tube,and also the gap between your sidewalls present in concrete piles are filled with liquid mud.This should be cleaned outside the spaces in the pile connection prior to tube hole along with the wall gap are grouted.The process is described below.

2.1 Step One:Isolating the liquid mud at the connection of two sheet piles

The mud must be isolated from the external way to obtain water and soil surrounding the piles to be taken out of the tube and the wall gap.The 2 vertical cylindrical holes A–A'and B–B'are built to make this happen.The isolation procedure is really as follows.

Both holes can also be filled with liquid mud,which will impact the grout when it arrived to direct connection with the mud.To safeguard the grout in the liquid mud in each one of the two holes,a protracted cylindrical bag is employed.The bag consists of thin flexible plastic sheeting which is extremely flexible.The bag is slightly wider and beyond the vertical cylindrical holes A–A'and B–B'.They have just one opening at its head.

A small amount of fresh and liquid grout is poured into the top bag and in a position to settle at its bottom.The foot of the hag will then be inserted in the hole A–A'.The gravity force from the fresh grout stretches the bag vertically and carries the bag bottom down with the vertical hole for the base inside the soil.Additional fresh grout is then poured in to the bag over the pile head under low pressure.The mud from the hole needs circulation out of the hole as a result of pressure with the fresh grout within the bag.Much the same procedure is employed for the whole B–B'(Fig.6).

As time passes,the liquid grout inside the two plastic bags in the holes A–A'and B–B'hardens.The hardened grout inside a bag fully contacts the concrete surface of the piles as shown in Fig.7 at Guang-nan reservoir.Consequently,the 2 hardened grout bags within the vertical holes A–A'and B–B'form two solid columns completely isolating the mud inside the tube along with the sidewall gap.

2.2 Step Two:Removing mud from the tube and wall gap

Subsequently,a steel pipe having a single nozzle at its end is inserted in the mud inside the rectangular tube at the pile connection.Clean water might be pumped in the bottom end-of the tube over the pipe to purge the mud out from the tube and also the wall gap.Because the isolation of the grouted bags,the mud could be washed out and substituted with clean water.The mud mixes together with the water that is clean and flows beyond holes on top of the tube as well as the wall gap.

2.3 Step Three:Grouting the tube with all the I-beam in the connection

Fresh grout will be pumped into the bottom end of the tube with the steel pipe.The new grout gradually fills inside the tube and the wall gap even though the water that is clean inside the tube and gap is being flushed out at the top because fresh grout is heavier than water.The process is completed when the fresh grout begins to flow out of the tube.

The steel pipe is then slowly pulled out of the tube which is tilled with fresh grout.The removal of the steel pipe may cause the fresh grout level in the tube and the wall gap to fall slightly and additional grout may be added.The grout should have a unit weight of 18 kN/m^3.

Fig.4 Jetting sheet pile driven at pile toe

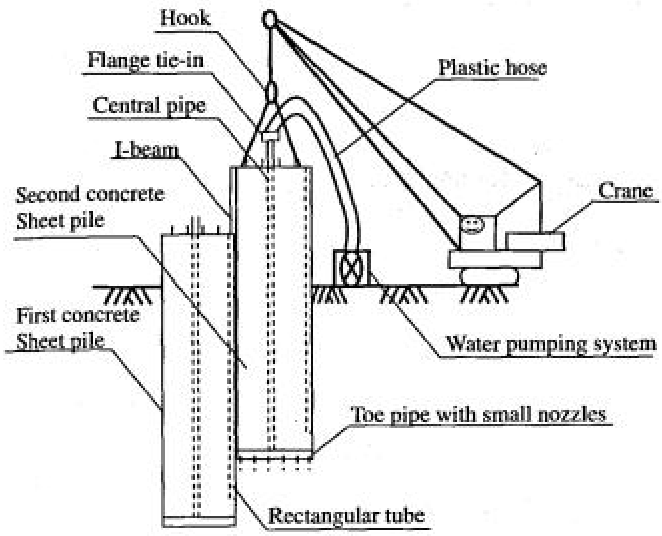


Fig.5 Horizontal cross-section showing initial connection between two sheet piles before grouting

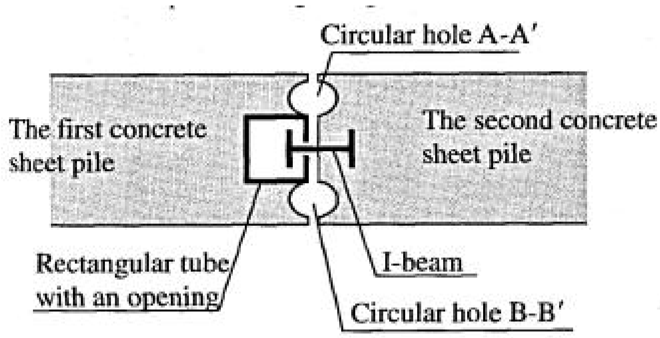


Fig.6 Details of the sheet pile design for the water discharge control lock

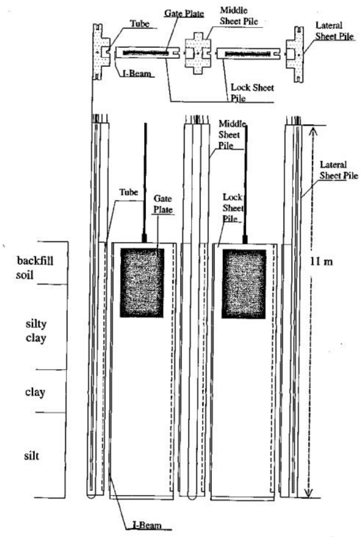
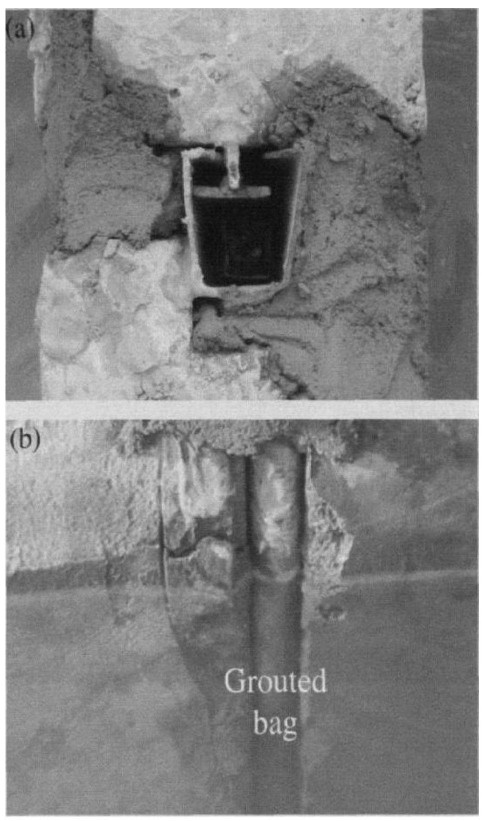


Fig.7 Photograph showing the steel tube and I-beam and internal spaces between two concrete sheet piles isolated with two grouted plastic bags within the two circular cylindrical boles.(a)Top view of isolated tube and wall gap.(b)Front view of a grouted plastic bag between two sheet piles



3. Grouting outside space of the toe pipe and central pipe

To further improve the structural strength of the pile the interior spaces from the toe pipe along with the central pipe should be grouted.Water that is clean is pumped in to the toe pipe from the steel pipe to purge out your mud within the toe pipe and also the central pipe.Fresh grout will be pumped in to the toe pipe to fill the internal spaces from the toe pipe as well as the central pipe.

The central steel pipe should be removed before cleaning and grouting.The concrete sheet pile must be designed and created to encourage the central pipe to become retrieved after pile installation.

4. Grouting for strengthening disturbed soils

The soils beneath and immediately close to the concrete sheet pile are disturbed and loosened.Although the disturbed soils are within 10-20 mm,it could be required to strengthen these with grouting.Fresh grout may be pumped in to the disturbed zones with the steel pipe after it can be inserted in to the pile toe area.As soon as the fresh grout completed the disturbed soil zones consolidates and harden,the grouted soils will have higher shear strength to support the pile.

5. Main construction steps

The grouted jetted precast concrete sheet piling method includes the following main construction steps:

(i) Casting specially designed concrete sheet piles for jetting,grouting,and connection

(ii) Jetting drive an automobile the precast concrete piles by their very own weight into soil from sometimes a floating or anchored piling platform

(iii) Cleaning and grouting the link zone between two concrete sheet piles as well as the internal pipes from the sheet piles

(iv) Grouting the disturbed soil zones beneath and close to the pile and

(v) Constructin g pile caps to integrate and strengthen the grouted and jetted precast concrete sheet piles.

6. Experiments and results

6.1 Jetting driving speed

The intention of the very first field trial was to discover the optimum jetting speed by varying the number of small nozzle holes and the jetting pressure.The experiment was conducted at the site in northern China on the mouth of the Yellow River.The soil had seven strata comprising clay,silty clay,and silt from ground surface into a depth of 14.4 m.The groundwater table was nearby the ground surface.The concrete sheet pile was 8.0 m in length,0.6 m wide,and 0.25 m in thickness.The central pipe diameter was 100 mm.Three toe pipes of equal size were used,one with 45 small nozzle holes,the 2nd with 100,as well as the third with 150.All of the holes had a uniform diameter of 3.2 mm.The pile was driven into soil for 7.3 m by jetting.Three different water pressures(0.7,1.0,and 1.3 MPa)were utilized.

The outcomes of such nine different combinations are listed in Table 1.Basically,the larger the number of nozzle holes and the better the water pressure,the faster the rate of installation.

Table 1 Results of the sheet pile driving speed by jetting with different pressure and nozzles.

Number of nozzles uniformly distributed on pile toe	Average cutting area per nozzle beneath pile toe(mm^2)	Pressure of jetted water(MPa)	Total time for driving pile 7.3 m into soil(min)	Driving speed(m/in in)
45	333(=600x25/45)	0.7	39.0	0.18

		1.0	30.5	0.24
		1.3	26.5	0.28
100	ISO(=600x25/100)	0.7	33.0	0.22
		1.0	19.0	0.38
		1.3	10.6	0.69
150	100 t=600x25/150)	0.7	DLO	0.26
		1.0	17.5	0.42
		1.3	8.0	0.91

6.2 Connection strength of sheet piles

Laboratory tests were performed to examine the strength of sheet piles in their connections(Fig.8).Three concrete panels(left,middle,and right)were utilized.A few panels were fixed together while using method described above,the place that the steel I-beam and tube were utilized because reinforcement for that grouting.The I-beam had its cross-section dimensions the next:flange length equal to 80 mm,web width corresponding to 40 mm,and wall thickness comparable to 4mm.The steel tube had its cross-section dimensions the subsequent:length corresponding to 80 mm,width corresponding to 60 m,wall thickness equal to 4 mm,and along with the opening gap comparable to 10 mm,each of the three concrete panels was 0.30 m in total,0.15 m wide,and 0.30 m in thickness.

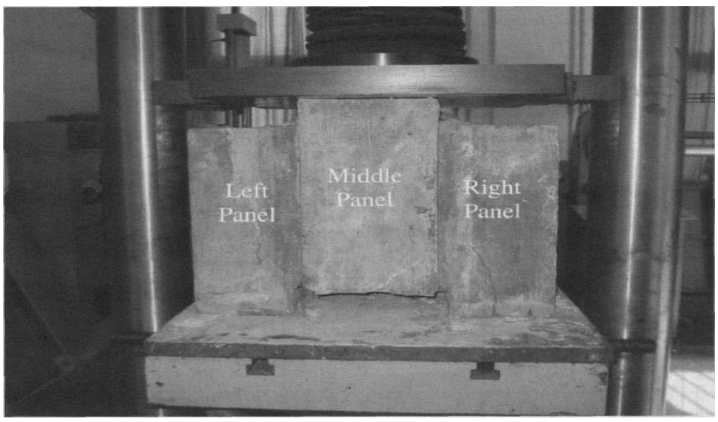


Fig.8 Laboratory setup for testing the connection strength of three concrete panels

The middle panel was placed 0.05 m over the left and right panels.The bond between your middle panel and every one of the other two panels was 0.25 m high and 0.30 m wide.Quality was completed about the 28th next day grouting of these two connections with the three panels.

The first steel plate was placed over the middle panel.An extra steel plate around the support platform was placed under the right and left panels.An axial load was placed on the initial steel plate about the upper top of the middle panel and was then transferred for the second steel plate using the left and right panels.

Three failure tests were conducted.The axial load for that failure on the two connections with the three panels was about 316 kN.The failures put together inside panel concrete for your steel I-beam or tube.The grouted connections between the left panel as well as the middle panel or relating to the middle panel and the right panel would not fail.The typical shear strength from the panel connections for several tests was equal to 2.1 MPa[i.e.,316 kN/(0.25 m x 0.30 m)12].

6.3 Static load tests of each sheet piles

Static pile load tests were performed on two individual concrete sheet piles at Guang-nan reservoir.The two sheet piles were jetted into ground at the site close to the mouth of the Yellow River.Both the sheet piles were 12 m long.Their cross-sections were rectangular and were 1 m wide and 0.3 m thick.The 2 piles were driven into the soil stratum completely by jetting.

The soils had these seven strata:silty clay,silt,silty clay,silt,clay,silt,and mud clay.The groundwater table was 3.5 m under the ground surface.The soil physical and mechanical properties are provided in Table 2.A conventional cone penetration test(CPT)was conducted at the website.The CPT tip and friction resistances with depths are shown in Figs.9 and 10,respectively.The CPT data demonstrates the sheet pile toe bearing soil stratum would have been a 2 m thick silt stratum using a CPT tip resistance of 4 MPa.This soil stratum was underlain by the weak mud clay using a CPT tip resistance of 1 MPa.Figs.11 and 12 show the axial load distributions over the first grouted sheet pile along with the second ungrouted sheet pile at different applied loading levels.

Table 2.Representative values of the soil physical and mechanical properties for static loading tests of single jetted sheet

Strata No	Soil type	Bottom depth(m)	Specific gravity	Natural water content (%)	Natural unit weight (kN/m^3)	Void ratio	Liquid limit (%)	Plastic limit(%)	Elastic modulus of deformation (MPa)	Cohesion (kPa)	Frictional angle (*)	CPT tip resistance (MPa)	CPT friction resistance (kPa)
1	Silty clay	4.8	2.68	19.4	20.0	0.61	25.1	14,1	6.3	11	35	1,6	30
2	Silt	9.4	2.67	27,2	19.7	0.73	29.7	21.4	19.4	9	36	2,4	30
3	Silty clay	9.9	2,70	35.7	18.9	0.94	34,9	19.8	4.2	8	21	1.0	10
4	Silt	10.6	2.68	26.5	19.7	0.72	29.0	21.1	181	10	33	2.0	30
5	Clay	11.9	2.74	40.3	18.1	1.14	45,2	22,3	3.2	3	6	0.8	8
6	Silt	13.9	2.67	23.8	20,1	0.66	28.6	20.3	20,0	8	40	4.0	40
7	Mud clay	17.4	2.74	45.7	17.5	1.28	42.8	21.3	4.4	6	11	1.0	10

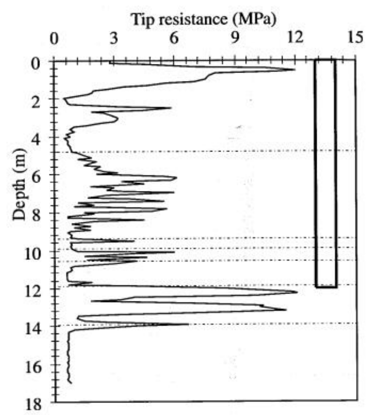


Fig.9 Tip resistance of cone penetration test in soil strata for pile loading test

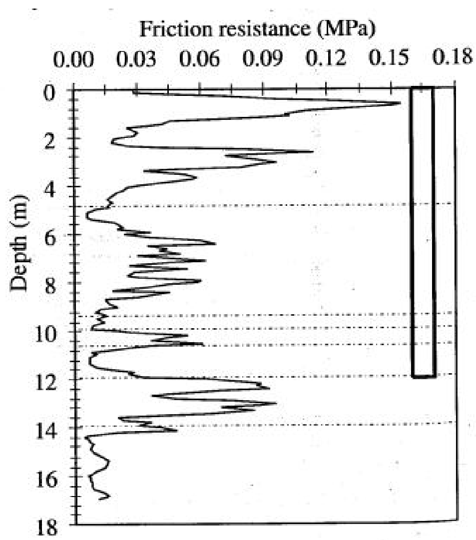


Fig.10 Friction resistance of cone penetration test in soil strata for pile loading test

The outcome showed in Figs.10-12 prompt the following observations:

- The 1st sheet pile stood a limiting bearing capacity of 540 kN and the second was 400 kN.
- The next pile had zero shaft resistance with the limiting load use of 400 kN.The limiting bearing capacity of 400 kN was mainly as a result of toe resistance,revealing the soil capacity in the pile was 13 MPa.
- The grout used on the disturbed soil zone to the first sheet pile evidently increased your skin layer and toe resistance with the surrounding soils.
- At the pile head settlement of 40 mm,the first and the second piles had bearing capacity values of 480 and 320 kN,respectively,which indicates that the grouting caused a net increase in the pile capacity of 50%[i.e.,(480-320)/320].

It is therefore evident that(i)the ungrouted sheet pile had adequate bearing capacity;and(ii)that the growing of disturbed soils improved the pile bearing capacity.

The disturbed soil zone close to the first sheet pile was strengthened by grouting.The grouting had not been placed on the 2nd sheet pile.The two piles were completely buried in soil strata.The static loading tests were conducted on the 60th next day pile installation.Strain gauges were also attached to the steel reinforcements present in sheet piles at different depths.

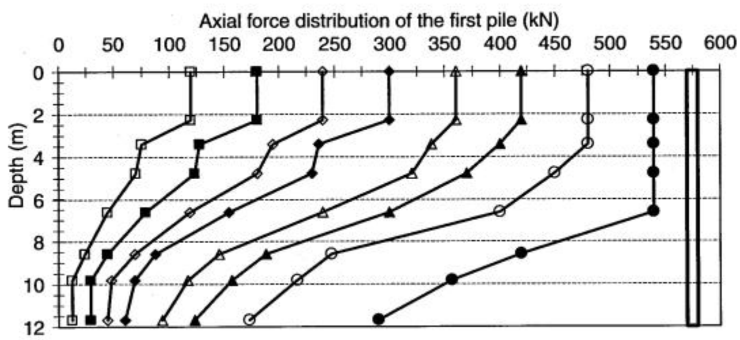


Fig.11 Axial force distribution with depth in the first sheet pile with grout.

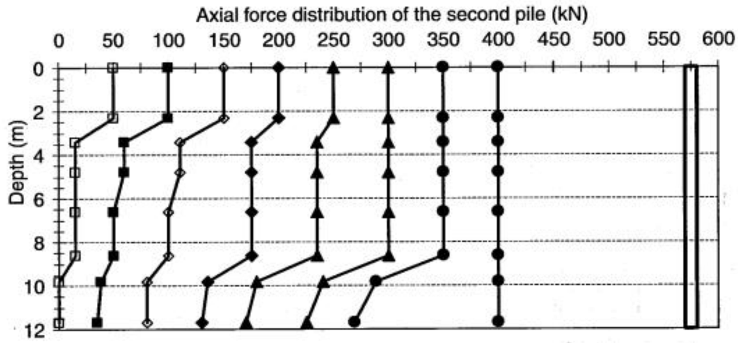


Fig.12 Axial force distribution with depth in the second sheet pile without grout.

7. Applications

7.1 Breakwater

A breakwater was integrated July 1998 with a coastal site in northern China for the shore in the Bohai Sea near an early mouth with the Yellow River.The breakwater was constructed while using grouted jetted precast sheet piling method.The purpose of the experiment would have been to see whether this breakwater could resist heavy seabed erosion.

In recent times,the ocean has encroached severely for the southern shores in the Bohai Sea.The shore and seabed on the breakwater site were originally formed as a result of the deposition of sediment at one of several mouths of the Yellow River.In 1976,this kind of mouth run out,as well as the Yellow River started to discharge its main flow at Qing-shui-gou.Because of this,sediment deposition in the breakwater site ended.Many years later,the Bohai Sea did start to encroach on the webpage and drowning a large land area.A protracted protective embankment was built along the new shoreline in order to avoid further encroachment.However,continued erosion has lowered the seabed and weakened the embankment foundation soils.

The breakwater was located 30 tri away from main embankment.In addition to the concrete sheet piles,concrete T-shaped piles were also used.Each pile was 1.2 m wide,0.3 m thick,and 16.0 m long.Towards the top of the break-water,steel reinforcements 0.3 m high were preset and left afterwards construction of pile cap beams with the cast-in-place method.T-shaped piles were added for lateral support behind the front wall in the breakwater at 6.0 m intervals.Each T-shaped pile was associated with two sheet piles parallel to the front wall as well as a third sheet pile perpendicular for the front wall.Each T-shaped pile was linked with one other three sheet piles by one I-beam and two rectangular tubes.The third sheet pile was 2 m wide,0.3 m thick,and 16 m long.

Right after the breakwater was finished the piles were immersed in 3 m of seawater,and their bases were buried in 10.5 m of soil.The tops protruded 2.5 m above the water.The reinforced concrete capping was 0.4 m high and 0.3 in wide.The building blocks soils were mainly fine soils.Their physical and mechanical properties are similar to those succumbed Tables 1 and two.Between 1998 and 2002,the seabed as you're watching breakwater had eroded to some depth of approximately 1 m by wave action.Presently,the breakwater remains standing.

7.2 Water discharge control lock

A water discharge control lock seemed to be built with the main mouth of the Yellow River.The lock was constructed in 1997 together with the grouted jetted precast concrete piling method.The precast concrete sheet piles were built with a total length of 11m.Three forms of sheet piles were made and used:lateral sheet piles,middle sheet piles,and lock sheet piles.The lock sheet pile is open in the upper portion,in which a gate plate is installed for manipulating the water drainage

over the control lock.
The thickness of the sheet piles buried in soil was 0.65 m.The piles had their lower 6.0 in buried in the soils.The soils were mainly clay and silt.The primary bearing soil was shown in Fig.10,as well as the fluctuation from the river water level was ready 2 m.Since 1997,the lock has been functioning well.

7.3 Wastewater treatment pools

The piling method seemed to be used to construct several wastewater treatment pools in 2000 near Wang-jia-gang Village.Each pool was 3.5 m deep,15 m wide,and 56 m long,and it was constructed by excavation.The excavated pit depth was 4 m.The soils were mainly silt and silty clay.Before excavation,precast sheet piles were installed by jetting and after that grouted together in-location to form impervious diaphragm walls,each individual sheet pile was 7.5 m long,1.20 m wide,and 0.25 m thick.After grouting,the capping beams with the walls were constructed from the cast-in-place method.The sheet piles had steel bars 0.2 m long for the pile head.These vertical bars were further linked with the horizontal steel bars for your wall capping beams.After completing the excavation,a geotextile along with a rock fill layer were put on the excavated base of the pool.An impervious concrete plate base ended up being constructed by cast-in position with steel reinforcements.So far,the pools have already been functioning well.

Conclusion

Jetting for pile driving has lots of advantages.Specifically,it will no harm to environmental surroundings and is an efficient technique.However,conventional jetting methods produce a large disturbed and liquefied soil zone around the pile that may significantly reduce pile bearing capacity with techniques tough to predict.
Pile jetting method had minimizes the extent from the disturbed zone adjacent to the pile and gives greater control over the piling process.The new technique generates uniform streams of highly pressurized water from many small nozzle holes with the pile toe,minimizing disturbance for the surrounding soils and conserving their shear strength.We have also presented a progressive grouting strategy to lock and seal together sheet piles in order to create continuous pile groups and/or diaphragm walls.This ensures the standard of the text grouting for adjacent sheet piles.
Four experiments and their effects were shown to demonstrate:
(i)The top jetting efficiency
(ii)The top grouting strength for sheet pile connection
(iii)The prime pile bearing capacities with and without grouting of disturbed soil zone adjacent to the pile and the narrow disturbed soil zone,respectively.We have also presented some practical values of the design parameters for jetting and grouting.These practical values were obtained from trials near the mouth of the Yellow River.They are useful for further applications in other similar ground regions.
Finally,we have described three practical applications of the proposed jetted grouted precast concrete sheet piling method in building projects in sites near the mouth of the Yellow River.These applications were selected from more than 20 such projects in the region over the past 10 years,including seawalls,breakwaters,bridges,and wharfs of piers,bridge piles,and culvert piles,diaphragm walls for wastewater pools,water flow control locks,and water flow discharge channels.We have also shown that the proposed method can be used in a range of civil engineering projects in coastal regions where the main soil types are sediments and the water is shallow.

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